2445 Cajun Drive
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Jan 8, 86

Paul,
Please find enclosed my paper dealing with Amateur Packet Radio Networking. I do not want to present it at Orlando but would like it to be distributed as a "discussion document".
Don't be alarmed by the combination of call and address - I am on tempory assignment here with IBM!

Regards,

Tony Dawes

Tony Dawes G6VZF

Packet Radio Networking

January 4, 1986

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PREFACE

This paper is an attempt to summarize what I have learnt about Packet Radio, some of the shortcomings I have experienced and some ideas on potential future enhancements to the protocols. Some of the content will be technical in nature and may be out of line with some other current ideas. However, I feel that all input on the subject is useful at this time.

Contents

List of Illustrations

BACKGROUND

First, a little of my background, both in Amateur Radio and also in the field of network technologies.

AMATEUR RADIO

I have been active on Amateur Radio for only a few years but have used 2m FM and sideband, ATV, FM and sideband on 70cm, RTTY and AMTOR on 2m, worked through Oscar and RS satellites, and, under the supervision of a UK Class A licence holder, worked numerous HF bands. And now Packet Radio, more of which later.

NETWORKING

As part of my employment with a major computer manufacturer, I have maintained both the hardware and software of telecommunications networks, taught hardware and software network theory and problem determination to both customers and engineers, and also been heavily involved with the design and implementation of TP networks. These networks have brought me into contact with most protocols currently in use. These are link, transport and session protocols - all of which are of concern in this new field of Amateur Packet Radio.

SHORTCOMINGS

Working one's way around the country on 2m Packet is fine if :

1. you have a list of digipeaters

2. you know where they are

3. you do not use more than 8 of them

This list is, I believe, the stumbling block to Amateur Packet activity. I know that I am not alone in thinking that.

The other major problem is, of course, overcrowding on certain frequencies, particularly 145.010MHz in Georgia. I am sure that this story is repeated wherever Packet is prospering. This problem would be alleviated, if not removed altogether, if a solution to the three problems outlined above were to be found. That is more or less where the debate is at the moment, with the exception of some addressing ideas which I shall cover later.

PROBLEM RESOLUTION

AX.25 is based on the CCITT recommendation X.25 (and many others which cover different parts of the transmission system). It would be appropriate to look at X.25 protocols in some detail before comparing them with the AX.25 implementation.

Note: I make no apologies for re-visiting X.25 - I believe that the original protocol still has much more to offer.

CCITT X25

As already stated, packet transmission relies on many protocols to control different elements of the system. The total us usually referred to as "X.25" for clarity.

An X.25 node can be considered to be made up of a number of layers.

Physical Layer

This defines the electrical characteristics of the interface between the DTE and DCE. In most Amateur Radio applications, the interface used is RS232-C. This defines not only voltage levels but also handshaking protocols between DTE and DCE.

Link Layer

The link-level protocol is the method by which packets of data are transmitted around the network. This protocol is HDLC in AX.25 applications but may, theoretically, be any link protocol such as BSC or even Start Stop. HDLC is the best choice as it offers superior error checking, addressability, message queueing and lost message recovery.

Network Layer

The Network layer is comprised of a number of "sub-layers". To and end user, i.e. the Ham at each end, there is only one Network layer. This is the layer responsible for managing the communications with the other station. This layer is responsible for:

1. Establishing communication (connection) with another station.

2. Responding to data packets received.

3. Performing packet level error recovery.

4. Ending (disconnecting) communication.

Within an intermediate network node (INN), this layer is also used for communication with other INNs.

Session Layer

The session layer is outside the control of the network itself. All of the previous layers are "built in" to the X.25 protocol. The Session layer must be managed by the end user. A Session is defined as being the rules by which two end users will communicate. For example,

1. How and when will responses be sent?

2. Who is responsible for error recovery?

3. Can message flow be interrupted?

These are but a few of the rules required before a Session can be established.

Presentation Layer

This layer is responsible for the format of the user data contained within the packet. User data is transparent to the network once within a packet. For example, if 8-bit ASCII is used by the Link and Network layers, any other code (e.g. 6-bit transcode) may be used within the user's data portion of the packet.

Application Layer

This layer is intended for use by intelligent applications communicating with one another. X.25 has no definition for this layer other than that it exists. All protocols used at this layer are the responsibility of the applications. For example, a document-processing application may define its own commands in order to identify different types of document or request.

X.25 NETWORK

This section will describe the operation of the first three layers,

1. Physical

2. Link

3. Network

The following figure is a simplified example of an X.25 network.

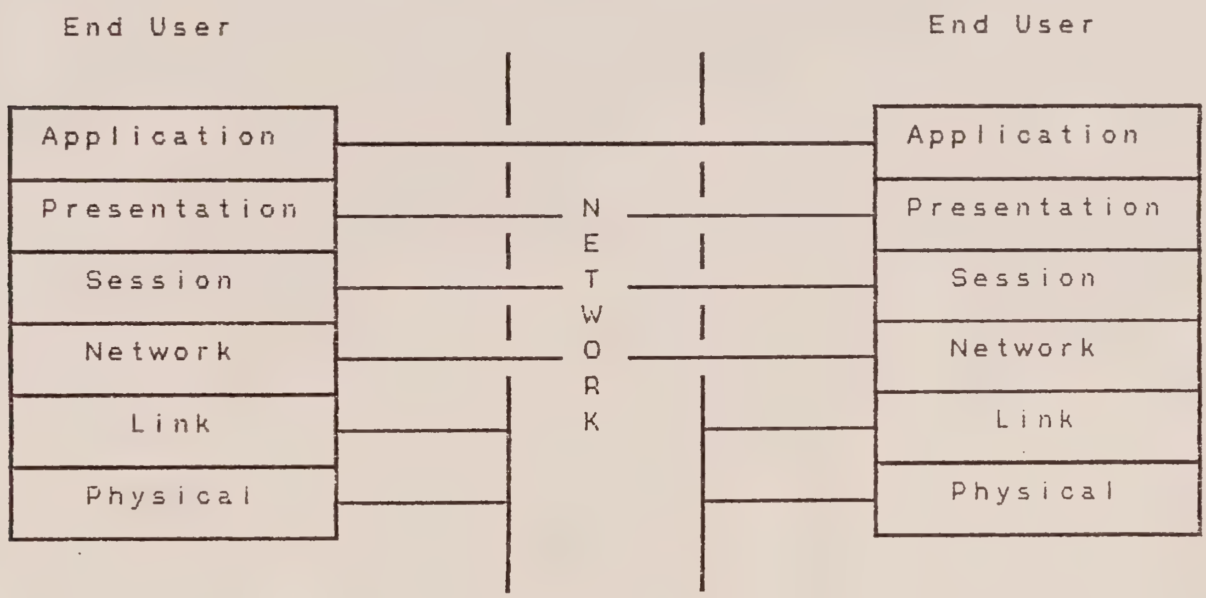

Figure 1. Simplified X.25 Network

PHYSICAL LAYER

The process of establishing contact between the end users starts at the Physical layer - the RS232C protocol. This may occur as follows.

```
DTE                          DCE

DTR  ----------------------->
     <-----------------------  DSR
RTS  ----------------------->
     <-----------------------  CTS
```

Figure 2. RS232-C

Note: The exchange of Request To Send and Clear To Send may only when the DTE wishes to transmit. In some applications, RTS is always present. In others, the sequence shown above is not used at all.

LINK LAYER

Connection between the DTE and the network, or the first INN within the network, takes place at the Link level using HDLC protocols.

```
DTE                        Network

SABM ----------------------->
     <-----------------------  UA
```

Figure 3. Link Level

Connection is now established. Note that this connection is only between the DTE and the first node in the network, not with another DTE or end user. I will not cover all of the possible error conditions that may occur, as they are outside the scope of this paper.

HDLC

It is now appropriate to investigate the HDLC frame itself.

Flag	Address	Control	Information	FCS	Flag

Figure 4. HDLC Frame

Address

The Address in an HDLC frame is an octet (8 bits). This address is 01H when a command is issued from the DTE and 03H when the command is issued from the DCE. This is not appropriate for Amateur Radio applications where a longer address (i.e. a call-sign) is required.

Control

The Control field is another octet which performs a number of functions.

1. Identifies the frame as

    a. Command

    b. Response

    c. Information

2. Performs frame numbering

The control field definitions may be found in other documents.

Information

The Information field may contain

1. Nothing, if the frame is a command

2. A Command packet

3. A user data packet

The information field may contain as many bits as required as long as

1. The maximum length does not exceed that of the maximum packet length.

2. It it a multiple of 8 bits.

NETWORK LAYER

As already stated, the primary connection is between the DTE and DCE, that is to say, the End User (the Radio Amateur's station) and the first node in the network. It is now necessary to establish communication at the Network, or Packet, level. This is done by means of a "Connect Request" packet sent to the network in order to identify both the calling and the destination stations. The command flow may be as shown below.

```
DTE          TNC             Network              TNC          DTE
                         .                .
DTR  ------>             .                .
     <------ DSR         .                .         <------ DTR
RTS  ------>             .                .    DSR  ------>
     <------ CTS         .                .
                         .                .         <------ RTS
SABM  ================>  .                .    CTS  ------>
      <=============  UA .                .
                         .                .
                         .                . <==============  SABM
                         .                . UA  ===========>
                         .                .
CONNECT ************>    .                . *************>
        <*************** .                . <***********  UA
                         .                .
data  ***************    .                . ************  data
                         .                .
      <***************   .                . <******  DISCONNECT
UA    ***************>   .                . *************>
                         .                .
DISC  ================>  .                .
      <=============  UA .                . <==============  DISC
                         .                . UA  ===========>
                         .                .
```

Figure 5. X.25 Command flow

As can be seen, data and command flow through the network is transparent to the end user. We shall investigate what happens inside the network in a later section of this paper.

The Connect Request that is issued by one of the DTEs

contains (within the X.25 protocols) the subscriber number of the destination. This is analogous to a telephone number or call-sign. It is a unique identifier for the two stations.

Flow Control

Flow control is implemented at both the link and network layers. It may also be implemented at the application layer. DTE to Network flow control is at the link layer and uses the Receive Not Ready (RNR) HDLC frame in order to inform the DTE that the first node in the network is becoming congested with traffic. At the Network layer, INNs may withhold packet responses along with the RNR frame.

As each user-user connection uses a virtual circuit, and many virtual circuits may flow over a single physical circuit, this provides a means of controlling the flow both at the physical and the virtual circuit levels.

AMATEUR APPLICATIONS

The AX.25 protocol is, at present, a combination of the Link and Network protocols. Link connection is established and maintained on an end-to-end basis. That is, all commands and responses are sent from one end user to another via the network (digipeaters) or directly. There is no flow control and therefore a far greater use of network resources than is desirable.

Unlike X.25, the AX.25 user must be aware of not only the destination and the first node in the network, but also the intermediate nodes in the network. This produces a number of problems, such as a change in path, the loss of a digipeater and the limitation of 8 digipeaters in the connect request. In short, the user should have a much simpler connection process. In turn this leads to much more sophisticated network nodes other than the simple digipeaters currently in use.

The end user has three main requirements.

1. Connect to a known station at a known location via a known node in the network.

2. Call CQ to a known area via a known node in the network.

3. Monitor for calls.

CONNECT TO A KNOWN STATION

In order for an Amateur Radio operator to connect to another, three things must be known.

1. The call of the destination station.

2. The location of the destination station.

3. The call and frequency of the first node in the network.

Note: By "first node in the network" I mean the node closest to the station.

The command that the operator would issue to the TNC may look like:

```
CONNECT G6VZF AT IIIIII VIA K4ABC
```

where "IIIIII" is a the location of the destination

station.

The connect request is first be sent to "K4ABC", the first node in the network, and then forwarded to the nearest node to location "IIIIII". The connect request is then transmitted to "G6VZF".

Note: Network routing is discussed later in this paper.

CQ

In order to call CQ, two things must be known.

1. The location to which the CQ is to be sent.
2. The call and frequency of the first node in the network.

The command that the operator would issue to the TNC may look like:

```
CQ TO IIIIII VIA K4ABC
```

where "IIIIII" is a the location of the destination station.

The CQ is first be sent to "K4ABC", the first node in the network, and then forwarded to the nearest node to location "IIIIII", where it is retransmitted.

MONITOR

In the case that a station want to connect to the network in order to monitor calls, a link level connection must be established with the first network node.

The command that the operator would issue to the TNC may look like:

```
MONITOR K4ABC
```

This allows connect request packets to be sent to the station.

Another form of monitoring is for both link and network level connections. In this case, the station is either not monitoring a network node or does not know which network node to monitor. In this case the command is simply:

```
MONITOR
```

The station may now receive an SABM from any other station and respond with UA if the destination call is correct.

STATION LOCATION

This locator should take one of two forms (still to be decided), either latitude and longitude or the Maidenhead locator system. Numerous addressing schemes have been proposed, but I believe that only latitude and longitude or the Maidenhead system are viable for Amateur Radio use. Zip codes are fine for the USA but of no use to the rest of the world. Some form of zip code is used in many countries, but the formats are different and many areas do not have codes at all. Airfield codes have also been proposed, but most areas of the world are too far from the nearest airfield for this system to be of use. For example, Heathrow airport is "LHR", but the nearest airfield to my home in England may be White Whaltham. I do not know its identifier and I am sure that the majority of Radio Amateurs do not even know of its existence.

A latitude/longitude or Maidenhead system has many advantages. In order to route a packet through the network, a network node needs to know which is the next node to which the packet must be sent. In other words, should it go north, south, east or west? Airfield or zip codes turn this into a difficult process, involving extremely large look-up tables. A system based on latitude and longitude only requires simple calculations and a very small table. I will discuss network routing in more detail later in this paper.

Connection

As previously stated, current AX.25 combines some of the X.25 link and network connection and data transfer protocols. I believe that to fully implement networking, we must go back to the original protocol.

In order for a station to send a connect request or call CQ the station must first establish link-level communication. The HDLC command set is used for this, requiring only a change to the address field of the HDLC frame. The address field is now a 128-bit field containing the calls of the sending station and the network node. The originating station's call is contained within the first 64 bits of the field and the network node's call starting at the 65th bit. Connection may now be established between the two stations.

```
Station     TNC                  Network
                              .
DTR  ------>                  .
     <-----   DSR             .
RTS  ------>                  .
     <-----   CTS             .
                              .
SABM  =====================>  .
     <==================== UA .
                              .
```

Figure 6. Link Level Connection

The station may now send packets via the network node.

<u>Note:</u> Link level flow control may now be implemented between the network and the station.

A Connect Request packet may now be sent into the network. Once again, this is analogous to the X.25 implementation. The Connect Request packet contains the call and location of both the originating and destination stations. All packets follow the X.25 protocols, the only difference being the originating and destination station addresses.

NETWORK NODES

The network nodes must be capable of two operations:

1. Maintaining a link level connection with an end user station.

2. Forwarding packets.

Operating in this manner offers a number of advantages over the current implementation of the protocol.

1. Flow control, both inside and outside of the network, is possible.

2. Retry operations are only performed between two adjacent nodes. There should be very few occasions when an end to end retry is necessary.

3. A simple end-user interface is offered.

In order to function as a network node, the node must perform a number of operations.

1. Establish and maintain link level connections with multiple end user stations.

2. Establish and maintain link level connections with multiple network nodes.

3. Determine the path to take in order to transfer end user packets.

4. Perform error recovery between itself and adjacent nodes and end users.

5. Perform flow control between itself and adjacent nodes and end users.

Details of error recovery and flow control are not covered in this paper as they are described in detail in the <u>CCITT Recommendation X.25</u> documentation. As already mentioned, I see the main difference between X.25 and the Amateur Radio application as being addressing.

◇ A 64-bit call-sign in the HDLC frame instead of an 8-bit address.

◇ A call-sign and destination code within the packet instead of a subscriber number.

NETWORK OVERVIEW

An attempt has been made in some parts of the USA (particularly Georgia) to create some form of network based on Local Area Networks (LANs) and a "backbone" network to connect the LANs together. This, I believe, is the correct way in which to start implementing X.25 networking.

Local Area Networks

A LAN must perform two major functions.

1. Allow the connection of users within the LAN (including bulletin boards).

2. Allow the connection of users within the LAN to users outside of it.

The first function is accomplished much as it is today, with the end user seeing little or no difference with today's operation. The following examples show possible connections within a LAN.

```
 G6VZF        TNC                  Server                    TNC      W4ABC
                           .       K4ABC            .
                           .                        .
                           .                        .       <_____ DTR
                           .                        .   DSR _____>
                           .                        .
                           .              1         .       <_____ RTS
                           .                        .   CTS _____>
                           .                        .
                           .                        .<______________ SABM
                           .                        .UA ____________>
 DTR _____>                .                        .
      <_____  DSR          .                        .
 RTS _____>                .                        .
      <_____  CTS          .                        .
                           .                        .
 SABM ____________________>.      2                 .
      <_______________  UA .                        .
                           .                        .
CONNECT ***************>   .                        .***************>
      <*******************.                         .<************** UA
                           .                        .
 data ********************.                         .************** data
                           .                        .
      <*******************.                         .<******* DISCONNECT
 UA  ********************>.                         .**************>
                           .                        .
 DISC ____________________>.                        .
      <_______________  UA .                        .<_____________ DISC
                           .                        .UA ___________>
                           .                        .
```

Figure 7. LAN Connection - 1 of 3

This figure shows a successful connection between two end users within a LAN. The Server is a network node, but in this example there is no link outside of the LAN.

◇ The operator at station W4ABC issues the following command:

    MONITOR K4ABC

  This causes a link level connection between the end user and the LAN (1).

◇ The operator at station G6VZF wishes to connect to W4ABC within his own LAN and issues the command:

    CONNECT W4ABC VIA K4ABC

  This command causes not only the link level connection between G6VZF and K4ABC but also the Packet Connect Request, which is routed directly to W4ABC (2).

◇ Data now flows between the two stations via the server.

<u>Note:</u> The connect command issued by G6VZF does not require a location as the destination is within the same LAN. The destination portion of the address within the packet is blank (32H) and will be recognized as a local connection by the server.

If one of the stations (end user or server) receives a bad HDLC frame, the retry operation is only required between adjacent nodes, i.e. end user and server.

```
 G6VZF        TNC              Server               TNC      W4ABC
                          .     K4ABC        .
 RTS  ______>             .                  .          <______ DTR
      <______  CTS        .                  .      DSR  ______>
                          .                  .
 SABM ____________________> .                .          <______ RTS
      <________________ UA .                 .      CTS  ______>
                          .                  .
CONNECT ***************>.***                 .
                          .   **             .SABM  ____________>
                          .     ****         .<______________ UA
                          .         **       .
                          .           ***.***************>
      <*****************.                    .<************** UA
                          .                  .
 data *******************.                   .************** data
                          .                  .
      <*****************.                    .<******* DISCONNECT
 UA  ******************>.                    .**************>
                          .                  .
 DISC ____________________>.                 .
      <________________ UA.                  .<______________ DISC
                          .                  .UA ____________>
                          .                  .
```

Figure 8. LAN Connection - 2 of 3

In this example, station W4ABC has only made the TNC operational. The connect request from G6VZF causes the server to issue the SABM. If the SABM timed out, the server would have repeated the SABM a number of times, up to the retry count. At this time, the server responds to the connect request with a connection failure packet, indicating the cause of failure, i.e. no response from the destination station.

```
G6VZF        TNC                   Server                  TNC      W4ABC
                               .    K4ABC        .<******************
                               .                 .******************>
SABM  =========================>.                .<******************
    <===================== UA.                   .******************>
                               .                 .<******************
CONNECT ***************>.                        .******************>
                               .                 .UI  ================>
      <************ CLEAR.                       .<******************
                               .                 .******************>
```

Figure 9. LAN Connection - 3 of 3

In this example, station W4ABC is already connected to another station. The server is aware of this connection and responds to the connect request packet with a DTE Clear packet, containing a cause code of "number busy".

Note: An Unnumbered Information HDLC frame may also be sent from the server to the destination containing the connect request information from G6VZF.

The server must maintain a record of all currently active connections that are passing through the server. While this will result in larger processors, it will reduce the traffic flowing through the LAN, particularly in the case of a timeout - only the server must retry the connection, not the originator. This reduces network traffic for that particular operation by nearly 50%.

Georgia LANs

There is currently an attempt being made in the state of Georgia to introduce LANs to cover the entire state. The figure below shows an example of how a number of LANs may operate within the state.

Note: This is an example, not a description of any existing or projected LAN configuration.

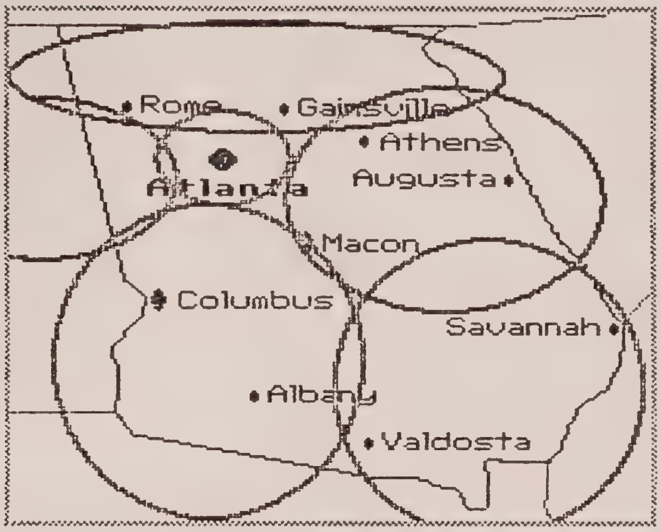

Figure 10. Georgia LAN Example

Using the protocols outlined above, stations will be able to connect to one another both inside and outside of their own LAN area. Each LAN will have its own server (digipeater).

Backbone Network

In order to pass traffic between LANs, a second type of network is required. This is the "backbone" network connecting the LANs together. Each LAN has a server which is also a gateway into the backbone network. Thus packets received on the LAN side can be routed into the backbone network and there to the destination station.

NETWORK ROUTING

In order to route packets through the network, intelligent network nodes are required. As already described, the end user interface requires very little routing information other than:

1. The call of the LAN server.

2. The destination call.

3. The location of the destination.

If a connect request is received by a server, and there is no "AT" in the request, that request is simply re-transmitted back into the LAN. If, however, a location is specified, the server must decide which is the next

node in the network to which the request must be sent. This may be achieved with a small look-up table and a little computing power as long as a latitude/longitude type system is used for destinations.

A latitude/longitude system requires 8 digits in order to obtain a resolution of approximately 10Km (7 miles), which should be adequate for LAN/network use. The latitudes and longitudes used are each four characters "llld", where "lll" is the latitude or longitude in degrees and "d" is one decimal place of degrees. Thus, if the required latitude is 45.2° and the longitude is 127.8°, then the destination would be described as "04521278".

Each server or LAN must therefore know its own location and the location of adjacent nodes. This sounds rather strange, but it is <u>only</u> the LAN servers and network nodes which require a destination. All other users within the LAN will use the destination code for that LAN.

The following scenario demonstrates how routing is to operate.

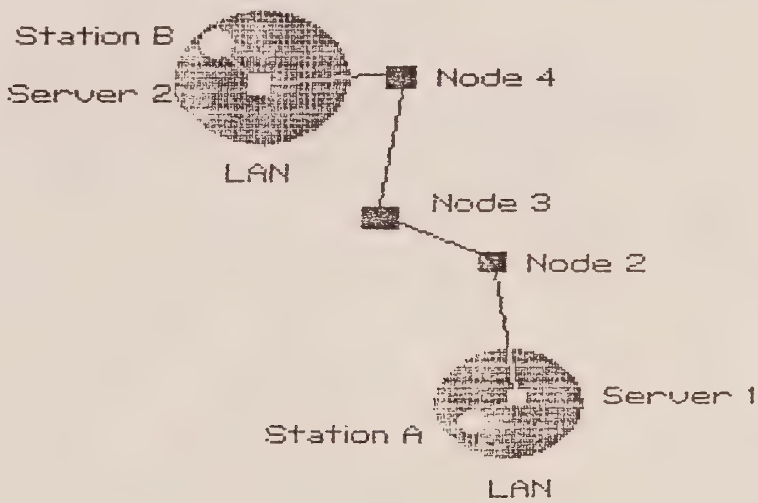

Figure 11. Network Routing

1. Server1 at location 30.3°N 93.6°W receives a connect request from StationA for StationB at 45.2°N 127.8°W.

   The operator at StationA enters the command:

   ```
   CONNECT STATIONB AT 04521278 VIA SERVER1
   or
   C STATIONB AT 04521278 V SERVER1
   ```

2. Server1 determines that the destination is northwest and that the next node is Node2.

3. Node2 receives the packet and determines that Node3 is the next node for the packet.

4. Node3 receives the packet and determines that the destination is Server5 by means of a look-up table.

5. Server5 receives the packet, determines that the LAN is the destination so re-transmits the connect request into the LAN.

6. The response, and any subsequent data traffic is then sent back to StationA using the same path.

In this example, there are two methods by which the network nodes may determine the path for a "virtual circuit".

1. Path determination by investigating the destination address of each packet.

2. Dynamically build a path table as the connect request flows.

Both of these methods have advantages and disadvantages.

Static Routing

If each packet determines its path through the network, network nodes must decide which path to take for individual packets. This results in more processing time for each packet and therefor increase the chances of network congestion as this processing takes place. This method does decrease somewhat the programming effort required within the network node.

Dynamic Routing

When a connect request flows through a node, the node builds a table of the network path for that particular virtual circuit. When any subsequent packets flow over that circuit, the path is already known. When a disconnect or failure occurs, that routing information is deleted. This type of routing requires more programming effort than static routing but does allow for dynamic re-routing if an intermediate network node fails. The node is able to detect the loss of an adjacent node as the link level connection will be lost. An alternate path may then be constructed if other adjacent nodes are available.

ALTERNATIVE SOLUTION

The examples of network connection and routing shown above pre-suppose that all TNCs in use will follow this protocol. This is, of course, a fallacy as a large percentage of the 10,000 or so Packeteers will not be prepared, or able, to upgrade their TNCs. This is not to say that full X.25 implementation should not be attempted, but that an effort should be made to allow the two systems to co-exist until such time as all TNCs are X.25 compatible. Network Nodes must be able to respond to X.25 protocols as well as the current AX.25 system.

Multiple Connect

In order that an AX.25 station may make use of an X.25 network, the Network Node must have the ability to make multiple AX.25 connections. The AX.25 user would connect to the Network Node and then send a a connect request within an AX.25 data packet.

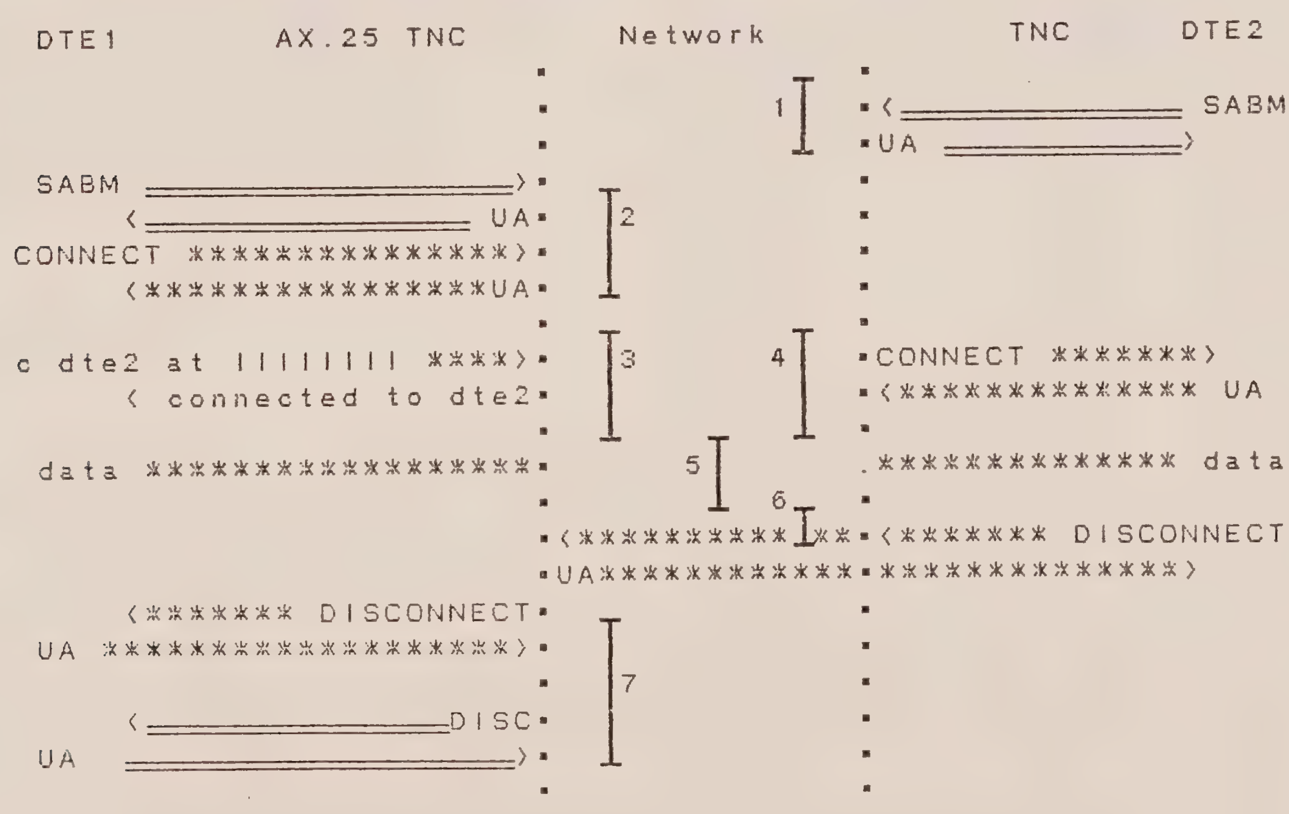

Figure 12. AX.25 to X.25 Command flow

The above figure illustrates the following scenario.

1. X.25 DTE2 makes a link-level connection to the network.

2. AX.25 DTE1 connects to the INN.

3. DTE1 sends a data packet containing a connect request.

4. The INN builds a Connect Request X.25 packet and routes it through the network to DTE2. DTE2 responds and that response is returned as a data packet to the AX.25 DTE1.

5. Data transfer now takes place.

6. DTE2 issues a Disconnect.

7. DTE1's INN disconnects from DTE1.

Thus the two systems may be made compatible.

Direct connection between an AX.25 station and an X.25 station may not be possible unless the X.25 TNCs support both protocols.

FUTURE APPLICATIONS

Once network nodes are communicating and network protocols are being implemented, the way is open for more advanced communications. Some of these will probably have to be cleared with the appropriate bodies (FCC in the USA, Home Office in the UK), but they will allow the hobby of Amateur Radio to broaden its horizons some more.

Round Table

In today's brass pounding and rag chewing communities (among others), a NET is generally a group of people shooting the breeze (or the Ether). With X.25 networking this is possible with packet. Each station would establish a session with a network node and then indicate at the Session level which other stations a in the NET. All packets from each station would then be forwarded to all others in the NET. An extension of this would be to allow stations to send "private" messages to one another while still in the NET.

Messages

Network nodes may be able to hold messages for stations that are not connected. If a message is sent to a disconnected station, the network node will hold the message until either the station connects to the network or the network node operator removes it. This is an extension of the BBS systems now in use.

SUMMARY

It is outside of the scope of this paper to detail the complete command, response and error flow through a network. The packet commands and responses should be those used by X.25, maintaining a virtual circuit at the packet level and a link level connection only between adjacent nodes.

Error recovery and flow control should also operate as defined by X.25 protocols. Virtual circuit window sizes should be determined by experiment, and may require an application layer session between network nodes in order to set up network flow parameters.

Using X.25 protocols allows end users (applications) to establish and maintain sessions without having to perform much, if any, error recovery. For example, file transfers may be performed using whatever protocols the end users decide upon. Flow control and error recovery are transparent to the application.

If there is enough interest in these proposals, my next paper on the subject will contain more detailed command and response flows, including network routing. It is, however, still all based on standard X.25 protocols. The major modification is with network addressing. Some form of latitude/longitude addressing must be used in order not to exclude a large proportion of the Amateur Radio community from Packet Radio.